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Where, When, and How Well People Park: A Phone Survey and Field Measurements

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16. Abstract

Two evaluations were completed to characterize where, how often, and how accurately people normally park. A telephone survey of 30 drivers examined where people park most frequently and the problems drivers have parking. The focus was on executing maneuvers, not the availability of parking. Depending on how the question was asked, approximately 74 to 84 percent of the parking events involved perpendicular parking. Of the 8 parking-related crashes reported by subjects, 6 involved backing, usually with a vehicle traveling down an aisle or backing up from a parking stall.

A field survey examined the parking accuracy of 102 vehicles in Ann Arbor, Michigan, a college town. For parallel parking, drivers parked about 4 in from the curb in spaces averaging 24 feet long. For angle parking, distances to the front of the space were bimodal, with some drivers parking about 10 inches from the end of the space and others overlapping by 10 in on average.

Overall, drivers parked slightly to the right of center (by 1 inch for parallel parking and 4 inches for perpendicular parking) for 8.5 feet wide spaces. Yaw angles were almost always less than 1 degree for perpendicular and angle parking, but as much as 3 degrees for parallel parking, which is a more difficult task.

The data from this experiment provide both a basis for establishing the conditions for parking experiments and baseline data on how well people park without assistance.

17. Key Words
Driving Performance, Parking, Accidents, Crashes, Motor Vehicles, ITS, Human Factors, Ergonomics, Safety, Usability, Telematics, Driver Vision

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WHERE, WHEN, AND HOW WELL PEOPLE PARK: A PHONE SURVEY AND FIELD MEASUREMENTS

UMTRI Technical Report 2004-18
December, 2004
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1 Primary Issues

1. According to the literature, how large should parking spaces be?
2. In what situations do people park most frequently?
3. What problems do people have parking and what kinds of crashes result?
4. How well do people think they park relative to others?
5. How do drivers think parking could be improved?
6. For parallel, angle, and perpendicular parking situations, what were typical sizes and distributions of parking spaces, and the vehicles parked in them?
7. For those parking situations above, what were typical values for longitudinal and lateral placement (e.g., distance to a curb for parallel parking), and yaw angle as a function of the vehicle type and/or vehicle size?

2 Methods

Literature Review – asked UMTRI civil engineers for definitive references on parking

Phone Survey (10-20 minutes/driver)

30 U.S. drivers

	Men	Women
Young (18-30)	5	5
Middle-aged (45-55)	5	5
Old (≥65)	5	5

11 questions concerning:

* vehicle driven (year, make, and model)
* annual mileage
* where park most often & type of space
* parking problems
* parking-related crashes they had
* ratings of how accurately they parked
* suggestions for improving parking

Field Measurements of Parking (in Ann Arbor, Michigan, USA)

102 vehicles

	Parking Situation		
	Angle	Parallel	Perpendicular
Car	24	22	28
Non-car	12	8	8

* vehicle make & model
* vehicle length & width
* adjacent vehicle make & model
* space type
* distance of vehicle to space boundaries

Results and Conclusions

Parking Space Size Recommendations from Civil Engineering Literature

	AASHTO Handbook	ITE Handbook
Parallel Parking	22-26 ft long	No recommendation
Perpendicular Parking	26-40 ft long	8.5, 9.0 or 9.5 ft w x 18.5 ft long

Parking Frequency

* Park about 3 times/day, weekend day-weekday frequencies are the same
* About 1/3 in parking lot, 1/3 involved parking at a residence (with a driveway)
* About 3/4 of all parking was perpendicular parking
* Few differences due to driver age or sex

Parking Crashes Reported

Maneuver	Crash Description
Backing **(6/8 crashes)**	Backing out and hit car 2 spaces down also backing out
	Turned too quickly into too small a space and got a big scratch on the side of the car
	Backed into pole
	Garage door down when backing out
	Backed up in aisle and hit her (another car)
	Passenger side corner hit adjacent vehicle when backing out
Entry	Turned forward into a spot and rear flare rim of wheel well hit other truck
Unknown	Driver's door side swipe, narrow garage

Parking Problems and Solutions Reported

About 75 % of the problems were related to backing, mostly exiting a parking spot

#	**Problem**
9	other vehicles (problems in seeing them)
9	small parking spaces
6	driver's vehicle (being difficult to maneuver or having a problematic front end shape)
5	driver perception (hard to gauge size of parking spot)
5	driver physical constraints (mainly neck mobility)
4	Other reasons

#	**Solution**
23	Parking spaces (14 said to increase space size)
10	Vehicles (6 said add sensors or cameras)
2	Drivers

How Well Drivers Think They Park

* 50% of sample said they park as rapidly as others, equal number slower and faster
* 47% said they park more accurately than others, another 47% said they were the same as others (sample bias toward parking more accurately).

Field Study of Parking

Vehicles in Sample – Samples Were Not the Same (Random Selection)

Situation	Value	Mean (in)	SD (in)	Minimum (in)	Maximum (in)
Perpendicular	Vehicle length (in)	**184**	10	169	206
	Vehicle width (in)	67	4	61	74
Parallel	Vehicle length (in)	**180**	7	166	192
	Vehicle width (in)	69	3	63	75
Angle	Vehicle length (in)	**177**	13	150	218
	Vehicle width (in)	66	4	60	79
Overall	Vehicle length (in)	181	11	150	218
	Vehicle width (in)	67	4	60	79

Key Parking Space Dimensions – Similar to Civil Engineering Recommendations

Situation	Value	Mean (in)	SD (in)	Min (in)	Max (in)	Distribution
Perpendicular	Width (in)	108 **(about 8.5 ft)**	4	98	114	Bimodal
Parallel	Length (in)	291 **(about 24-1/4 ft or 1.5 car lengths)**	60.	210	455	Negative exponential
Angle	Width (in)	107 **(about 8.5 ft)**	2	101	112	Normal

Measured Parking Positions in the Field

-Wall/barrier affects overlap for perpendicular and angle parking
-More yaw variability for parallel parking

Situation	Value	**Mean**	SD	Min	Max	Distribution
Perpendicular	Front distance (wall, no wall) (in)	**13, -5**	6.	2., -25.	28., 14.	Normal, mean varies with wall
	Left-right bias (in)	**- 4**	9.	-26.	14.	Normal
	Yaw angle (deg)	**0.1**	0.4	-0.7	0.7	Uncertain
Parallel	Front-rear bias (in)	**-8**	33.	-90.	49.	Log-normal
	Curb distance (in)	**4**	4.	0.	14.	Triangular
	Yaw angle (deg)	**-0.3**	1.7	-3.7	3.2	Normal
Angle	Closest front distance (in)	**-1**	14.	-24.	34.	Normal
	Left-right bias (in)	**-1**	5.	-11.	12.	Normal
	Yaw angle (deg)	**0.2**	0.4	-0.8	1.1	Normal

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INTRODUCTION

A noteworthy development over the past few years has been the growth in the electronics content of motor vehicles, in particular, computer-controlled systems. Examples include systems to control the engine and drive train, to control and deploy crash air bags, to present information to drivers, and many other applications. These systems have enhanced the efficiency, safety, usability, and convenience of motor vehicles.

Most of the safety research has focused on the most severe and life-threatening crashes. However, there are opportunities to reduce the relatively minor crashes that result in fewer injuries, and very few deaths, but substantial property damage. At a minimum, these minor crashes are extremely inconvenient.

A significant number of devices has emerged in the market to assist with parking and low-speed maneuvers, such as back-up aids (http://www.consumerreports.org/main/content/display_report.jsp?FOLDER%3C%3Efolder_id=399905; Consumer Reports, 2004). There are 2 common types of devices. On-board devices, using either sonar or cameras, alert the driver of close objects while backing. Nissan, for example, has installed a system for this purpose in recent models of the Infiniti Q45. Other off-board systems provide an auditory alert when moving forward and approaching an object, such as when pulling into a residential garage.

There are many other situations when parking and performing low-speed maneuvers for which appropriately-located video camera images may be useful to the driver. This particular project explores that topic. An initial report (Smith, Green, and Jacob, 2004) examined the literature and Michigan crash data, and provided insights from interviews with local insurance agents regarding parking and low-speed crashes.

That report concluded:

1. About 1/2 to 3/4 of parking crashes involve backing, often into another moving vehicle and typically while emerging from a parking stall.
2. Although angle parking has higher crash rates than those for perpendicular stalls, it is uncertain if this is because the angle parking is more likely to be on streets where speeds are higher than in parking lots and garages.
3. 8-1/2 foot wide stalls may have higher crash rates than wider stalls.
4. Most parallel parking crashes occur on major streets.
5. Lighting (day versus night) does not seem to be a factor in parking crashes.
6. Impairment to due alcohol and drugs is a very minor factor in parking crashes.

This second report seeks to characterize how often, where, and how accurately people park. The purpose of this information is to help guide the design of a parking assistance system, with special emphasis on application in the United States, as well identifying typical conditions of use and providing baseline data on how well drivers park now without assistance. Tests of prototypes that employ these conditions and other information will be described in subsequent reports.

Readers should keep in mind that much of the research literature relating to parking is somewhat dated, and the vehicle fleet has changed from predominantly passenger cars to a mix including light trucks, SUVs, and minivans. Furthermore, urban areas tend to be underrepresented in those studies, and since crashes are reported primarily for public property, parking lots are probably underrepresented. Nonetheless, the most important conclusions still should hold. In particular, the most common crashes involve a driver backing into another vehicle traveling down a parking aisle or another vehicle that is also backing up.

The existing data give a sense of the hazards, but risk is the product of hazard consequences and probability of exposure. Therefore, it is appropriate to collect data on exposure to parking, in particular any information that might be appropriate to help determine reasonable experimental conditions and typical parking performance.

How people park is determined by the parking situation (parallel, angle, perpendicular) and the size of the space. Some information on recommended parking space size appears in the AASHTO Green Book (American Association of State Highway and Transportation Officials, 2001). Because that reference concerns road design, the only parking discussed is parallel parking, with lane width being the focus. However, page 378 notes, “It has been found that most vehicles will parallel park within 150 to 300 mm (6 to 12 inches) of a curb face and on the average will occupy approximately 2.1 m (7 feet) of actual street space. Therefore, the desirable minimum width of a parking lane is 2.4 m (8 feet). However, to provide better clearance for the traveled way and to accommodate use of the parking lane during peak periods as a through-travel lane, a parking lane width of 3.0 to 3.6 m (9.8 to 11.8 feet) is desirable.” No source for the data on distance to the curb or vehicle size is provided.

Furthermore, Exhibit 4-31 (p. 379) provides additional information on parallel parking spot size (Figure 1), providing an example of how to transition a parking lane near an intersection with activity. Interestingly, typical space lengths are 22 to 26 feet.

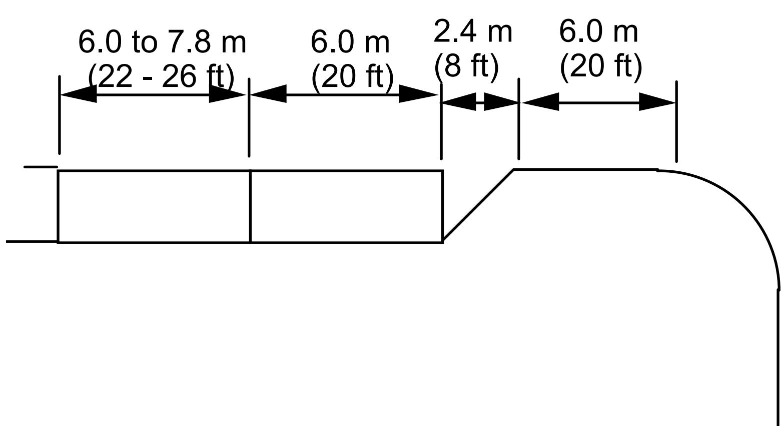


Figure 1. AASHTO Recommendations for Parallel Parking

The definitive reference on parking is the ITE Handbook (Homburger, 1982). Page 666 notes the following:

> *Three types of stalls must be considered in dimensioning curb parking facilities: end stall, interior stalls, and "paired parking stalls." The end stall, because a vehicle can either be driven directly into or out of it, need only be long enough to accommodate a parked vehicle. A length of 20 ft (6.1 m) is sufficient and is often used today. Interior stalls must allow room for maneuvering, and a stall of 22 to 26 ft (6.7 to 7.9 m) is recommended, which allows for 19-ft (5.8 m) vehicles.*
>
> *"Paired" parking has stall layouts so that two vehicles are parked bumper to bumper and pairs of stalls are separated by maneuver areas. Stall lengths of 18 to 20 ft (5.5 to 6.1 m) are recommended, with a well defined maneuver area of 8 to 10 ft (2.4 to 3.0m) (see Figure 2). A variation of the paired parking layout is the Travers Tandem Parking. This system expands the maneuver area to 16 ft (4.9 m), provides a minimum of 36 ft (11.0 m) of maneuver area, and allows for the driver to pull alongside the curb in one forward motion. Thus, traffic in the lane adjacent to the curb parking can proceed virtually uninterrupted. This system reduces somewhat the total number of curb spaces but improves the traffic flow in the curb lane.*

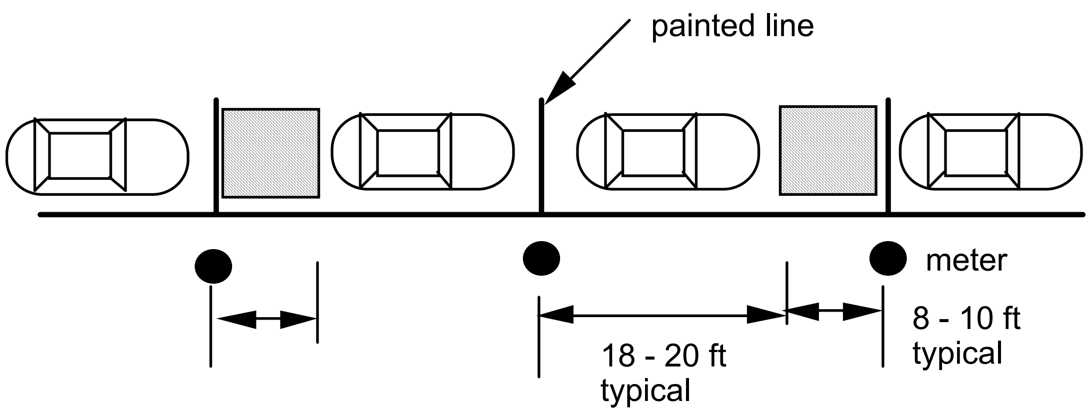


Figure 2. Paired Parking Layout

> *Curb spaces marked for compact cars can be smaller than the standard sizes shown above. A suitable design vehicle would be 15 ft long (4.6 m). Interior parking stalls at the curb are recommended to be 19 ft (5.8 m) long compared to the 23 ft (7.0 m) required for standard U.S. cars.*

The parallel parking recommendations are similar to those in the AASHTO Green Book. It is unknown if ITE adopted what was in the Green Book, the Green Book was adopted from an earlier version of the ITE Handbook, or both were based on a similar source. Both books cite a 1971 Highway Research Board report (National Academy of Sciences, 1971).

The AASHTO Green Book also provides dimensions for access to 18.5-foot long stalls of 8.5, 9.0 and 9.5 foot widths. No specific width is recommended, though page 649 of the handbook notes, "Substandard stall and aisle widths prove to be a false economy. Although this permits the marking of more stalls per given length, vehicles tend to encroach upon adjacent stalls so that one or more spaces are unavailable for use. The end result is no gain in actual space usage, but a parking condition surrounded by confusion."

Finally, the AASHTO Green Book cites Glanville (1970) and Sill (1968) listing parking standards in Europe. A summary of that data appears in Table 1. The sizes are smaller than the U.S. because vehicles in Europe, especially passenger cars, tend to be smaller.

Table 1. Parking Standards, Europe

Location	Stall width (ft-in, m)	Stall Length (ft-in, m)
General	7-1 to 8-2 (2.4 to 2.5)	15-7 to 16-5 (5.5 to 6.0)
Barcelona	7-10 (2.4)	15-7 (4.75)
Belgium	7-10 to 8-2 (2.4 to 2.5)	16-5 (5.0)
Germany	7-6 to 7-10 (2.3 to 2.4)	16-5 to 18-1 (5.0 to 5.5)
Madrid	7-10 (2.4)	16-5 (5.0)
Paris 30 deg	7-3 (2.2)	16-5 (5.0)
Paris 45 deg	7-6 (2.3)	16-5 (5.0)
Paris 90 deg	7-10 (2.4)	16-5 (5.0)
U.K.	7-10 to 8-3 (2.4 to 2.5)	15-7 to 16-5 (4.75 to 5.0)

Thus, existing design standards in the U.S. call for perpendicular parking spaces anywhere from 8.5 to 9.5 feet wide and 18.5 feet long. Parallel spaces are recommended to be from 22 to 30 feet long. However, it is important to keep in mind that these recommendations were developed some time ago, and the vehicle fleet has changed considerably since the early 1970s when the data for these recommendations were assembled. Specifically, vehicles were large before the 1972 oil embargo, smaller after it, and now growing in size as more light trucks and SUVs enter the fleet. Given the increased pressure for parking spaces, the U.S. recommendations deserve a fresh look.

To design a reasonable experiment, it is important to know not only how large parking spaces should be, but also how large they actually are, especially locally. Also important is the parking experience of local drivers and the local vehicle fleet, especially the mix of passenger cars and light trucks, which tends to vary from state to state, and between urban and rural settings.

Given this background, 7 questions were addressed.

1. According to the literature, how big should parking spaces be?
2. In what situations do people park most frequently?

3. What problems to people have parking and what kinds of crashes result?
4. How well do people think they park relative to others?
5. How do drivers think parking could be improved?
6. For parallel, angle, and perpendicular parking situations, what were typical sizes and distributions of parking spaces, and the vehicles parked in them?
7. For those parking situations above, what were typical values for longitudinal and lateral placement (e.g., distance to a curb for parallel parking), and yaw angle as a function of the vehicle type and/or vehicle size?

To address these questions, 2 evaluations were completed to characterize where, how often, and how accurately people park their vehicles. Additionally, the civil engineering literature pertaining to parking was examined. A telephone survey explored where people park most frequently and the problems drivers have parking. The focus was on executing maneuvers, not the availability of parking.

A field survey was performed to collect data on the location of parked vehicles in relation to parking markings and adjacent vehicles. Distances to forward and rear vehicles and the curb were measured for parallel parking, and distances to adjacent parking guidelines and the front barrier were measured for perpendicular and angle parking.

PHONE SURVEY OF PARKING - TEST PLAN

Survey Participants

To obtain data on where do drivers park and the problems they have, 30 drivers volunteered to respond to a phone survey (Appendix A). In that group of 30, 10 drivers were young (18 to 30, mean of 25), 10 middle-aged (45 to 55, mean of 51), and 10 old (≥65, mean of 69). Within each age group, there were 5 men and 5 women. Participants were either friends of the experimenters or had participated in previous UMTRI driver interface studies. Although the survey was administered in Ann Arbor and about 75 percent of the participants were from the greater Ann Arbor area, participants were drawn from 4 states and 4 different geographic areas across Michigan.

Participants reported driving a wide range of vehicles, with half driving cars and half driving light trucks, minivans, and SUVs, which reflects the current U.S. national production mix. The mean vehicle age was just under 4 years with a range of 0 to 10. Participants averaged slightly less than 1 hour per day of driving, with a range of 15 minutes to 2 hours.

Survey Form

The survey (Appendix A) consisted of 11 questions concerning the vehicle respondents drive (question 1), how much they drive (question 2), where they park and the type of space, both most often as well as most recently (questions 3, 11), problems associated with parking (questions 4, 5, 6), and parking-related crashes they had (question 7). Also examined were ratings of how well they parked (questions 8, 9) and suggestions for improving parking (question 10).

Survey Administration

Participants were contacted solely over the telephone. Sessions lasted 10-20 minutes depending on the subject. Participants were called early in the week (Monday and Tuesday) to facilitate recall of weekend parking. Questions were asked in the order listed on the survey (Appendix A). If a participant did not fully understand a question, that question was repeated as many times as needed. Experimenters refrained from offering additional explanation so question language was consistent. There were no follow-up questions to expand participant responses.

PHONE SURVEY OF PARKING - RESULTS

Where Do Drivers Say They Park?

Initially, participants listed the three primary locations at which they parked most frequently and the parking situation (parallel, etc.) at each location (question 3). Except for 2 participants (who only recalled 2 locations), all other participants provided 3 locations as requested.

Table 2 shows where participants parked most frequently and the type of parking space at that location. The data were pooled across age due to the lack of age interactions. However, the space type and location factors were not independent (Chi-Square (15)=173, p<.0001). Almost always, perpendicular parking occurred in a parking lot or residence (including garages at home) and parallel parking occurred on the street. Overall, almost 3/4 of the parking was perpendicular parking, with parallel and angle parking representing 17 and 9 percent, respectively. Thus, based on frequency, perpendicular parking deserves the most attention. In terms of location, about 1/3 of the parking was in lots, and the other 1/3 at a residence, most likely in a small lot at an apartment complex.

Table 2. Parking Type and Location
(Not available data have been omitted from the percentages.)

Location	Perpendicular	Parallel	Angle	Missing Data	Total
Parking Lot	27	1	3	0	31 (35%)
Residence	27	1	1	0	29 (33%)
Commercial	10	0	4	0	14 (16%)
Street	0	13	0	0	13 (15%)
Parking Structure	1	0	0	0	1 (1%)
Missing Data	0	0	0	2	2 (0%)
Total	65 (74%)	15 (17%)	8 (9%)	2 (0%)	90

Notes:

Location	Explanation
Parking Lot	Includes schools, shopping centers, or large lots
Residence	Includes any reference to a house or apartment with a driveway
Commercial	Used when a specific place of business was mentioned (may have some overlap with commercial and parking lot designations)
Street	
Parking Structure	Used for parking garages not at a residence
Missing Data	Indicates no third response from 2 subjects

At the end of the survey (question 11), participants listed how many times they parked in various types of spaces during the last 2 weekdays and weekend days. Table 3 shows the data by age group for weekdays and weekends. Overall, approximately 80 percent of the parking events were perpendicular parking, with parallel and angle parking occurring roughly equally often. There were few weekday-weekend differences in parking (even though people mostly just to go work in the week) as well as no age*parking situation interactions, though middle-aged subjects parked more frequently than young or old subjects. It was initially thought that there would be more parking events on the weekends because those days are commonly used for errands.

Table 3. Mean Reported Number of Parking Events per Week day and Weekend Day

			Parking Situation		
When	Age Group	Total	Perpendicular	Parallel	Angle
Weekday	Young	2.9	2.5	0.3	0.2
	Middle-aged	4.2	3.9	0.1	0.2
	Old	2.5	1.9	0.3	0.3
	Total	3.2	2.7	0.2	0.2
Weekend	Young	3.0	2.2	0.3	0.6
	Middle-aged	3.6	3.1	0.1	0.4
	Old	2.3	1.9	0.3	0.2
	Total	2.9	2.4	0.2	0.4
Overall Mean Total		3.1	2.6 (84%)	0.2 (6%)	.3 (10%)

These values were similar, but not identical, to the overall estimates for question 3 (Table 4) that concerned where people frequently park. Here, the percentage of maneuvers associated with perpendicular parking is more frequent (84 versus 74 percent), parallel parking is much less frequent (6% versus 17%) and angle parking is about the same (10 percent versus 9 percent). Problems associated with leaving spots were more common than those when entering (by 2:1) and backing problems outnumbered entry problems by 3:1.

What Problems Do Drivers Have Parking?

Table 4 shows the frequency of problems reported by subjects. Notice that about 2/3 of the problems were associated with backing while leaving a parking spot. There was no evidence of any substantial differences due to age. It was hypothesized that older drivers would report more problems with backing because limited neck mobility would make rearward visibility more challenging for them.

Table 4. Parking Problems Reported by Subjects
(Not applicable data have been omitted from direction percentages)

Most Problematic Task	Direction			Totals
	Forward	Reverse	Not Applicable	
Entering	7	2	0	9 (30%)
Equal	0	0	2	2 (7%)
Leaving	0	19	0	19 (63%)
Totals	7 (25%)	21 (75%)	2	30 (100%)

What Parking Crashes Did Drivers Report?

In addition to making parking easier, an important goal of this project was to make parking safer. Of the 30 subjects, 8 reported being involved in parking-related crashes (Table 5), with most crashes involving backing. There were no age differences in terms of the distribution of the number of crashes.

Table 5. Subject Descriptions of Parking Crashes in Which They Were Involved

Age, Sex	Movement	Description
young, female	backing	Backing out and car 2 down also backing out, hit each other
young, female	Unknown	Driver's door side swipe, narrow garage
young, female	Backing	Leaving perpendicular space, turned too quickly for the small space and big scratch on side of the car
middle age, female	Backing	Backed into pole
middle age, male	Bntry	Longer wheel base/turn radius; turned forward into a spot and rear flare rim of wheel well hit other truck
middle age, male	Backing	Garage door down when backing out
old, female	Backing	Backed up in aisle and hit her
old, male	Backing	Passenger side corner hit adjacent object when backing out

How Well Do Drivers Say They Park?

When fielding new technology, one must consider whether the technology has the capability to solve a problem and if that solution will be acceptable to potential users. In this case, if people thought they parked poorly, they might be very open to an assistive device. The parking data support the truism that most people report they are above average. In terms of accuracy (Table 6), only 2 subjects reported they were less accurate than average, whereas the remaining 28 were evenly split between being the same as others and being more accurate. One inference is that drivers could suggest that parking assistance devices are for others (as the others do not park as well).

Interestingly, in terms of parking speed (which is not viewed as much of a virtue), those reporting to be faster and slower than typical were approximately equal in number.

Table 6. Reported Speed and Accuracy of Parking

Speed	Accuracy			Totals
	More Accurate	Same	Less Accurate	
Faster	4	4	0	8 (27%)
Same	7	8	0	15 (50%)
Slower	3	2	2	7 (23%)
Totals	14 (47%)	14 (47%)	2 (7%)	30 (100%)

As shown in Table 7, there was a very slight tendency for the youngest drivers to report that they did not park as well as the middle-aged and older age drivers. Thus, if realizing that one does not park very well is an important aspect of the marketing of parking assistance devices, younger drivers are more likely to be a better target segment.

Table 7. Reported Parking Accuracy by Age Group

Accuracy	Age Group			Total
	Young	Middle-Aged	Old	
More Accurate	3	5	6	14 (47%)
Same	6	4	4	14 (47%)
Less Accurate	1	1	0	2 (7%)
Total	10 (33%)	10 (33%)	10 (33%)	30 (100%)

Why Is Parking Difficult and How Could Parking Be Improved?

To make parking easier and safer, it is important to know what drivers consider the problems and solutions. To obtain information on problems, free response comments were obtained from a sample of drivers on why they believe parking is difficult. (See Appendix C.) No single explanation predominated, though comments relating to seeing other vehicles were most common. Comments concerned driver perception (5 comments, hard to gauge size of parking spot), driver physical constraints (5 comments, many related to neck mobility), the driver's vehicle (6 comments, difficult to maneuver or having a problematic front end shape), other vehicles (9 comments, problems in seeing them), small parking spaces (9 comments), and other reasons (4 comments).

The solutions to parking problems, obtained as free response comments, appear in Appendix D. Comments concerned, parking spaces (23), vehicles (10), and drivers (2). Of those comments, increasing parking space size was mentioned 14 times and sensors or cameras were mentioned 6 times. All other reasons were mentioned once. Thus, respondents felt the solution was likely to come from an improvement in the parking situation, not the vehicle, though they did suggest vehicle solutions fairly often.

FIELD MEASUREMENTS OF PARKING QUALITY – PROCEDURE

To obtain baseline data on how well people park, measurements were taken of 102 vehicles parked in parallel, angled, and perpendicular parking spaces. Data was collected in Ann Arbor, Michigan, a college town (population 110,000) in the midwest United States. The parking locations chosen for each of the 3 situations were typical for Ann Arbor. Data was collected between the hours of 9:00 a.m., and 5:00 p.m., on 3 separate days.

A 25-foot. tape measure was held level by the 2 experimenters and measurements were recorded to the nearest inch. For painted lines, distances were measured to the closest edge, not the centerline. Only spaces between 2 parked vehicles were examined. If the vehicles surrounding the test vehicle moved while measurements were being taken, the incomplete data set for that space was discarded.

Tables 8, 9, and 10 show the dimensions collected and parking locations examined for parallel, angle, and perpendicular parking respectively. Appendix B contains notes and exceptions to the measurement procedure.

Table 8. Parallel Parking Measurement Information

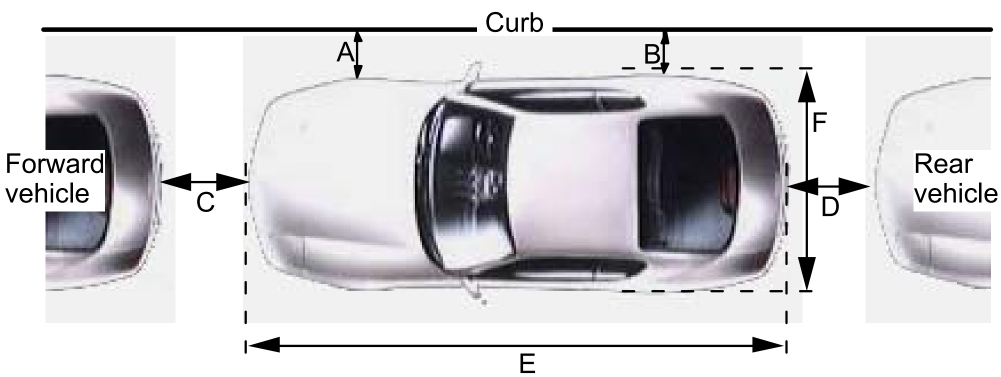
Situation	Parallel
Definition	The length of the vehicle runs parallel and is adjacent to the roadway and/or curb. Other vehicles are parked directly at the front and rear of the vehicle.
Vehicles measured	36
Locations	S. State St., between S. University Ave. and E. William St. Ann Arbor, MI
Diagram	 A. Center of front tire to curb B. Center of rear tire to curb C. Forward-most point of vehicle to rear-most point of forward vehicle D. Rear-most point of vehicle to forward-most point of rear vehicle E. Vehicle length from forward-most point to rear-most point F. Vehicle width
Picture	

Table 9. Angled Parking Measurement information

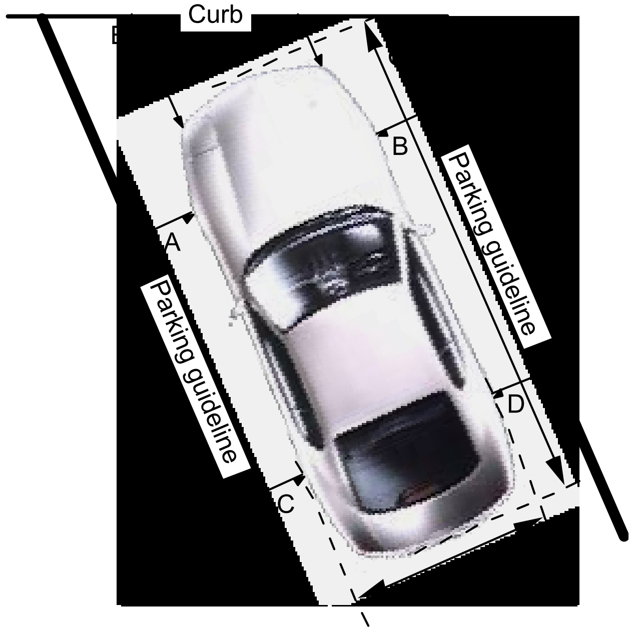
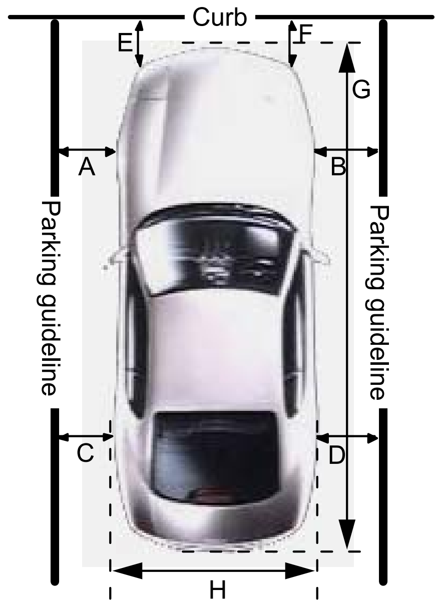
Situation	Angled	
Definition	The length of the vehicle and parking guidelines are perpendicular to the forward parking barrier. Other vehicles are parked on either side of the vehicle, all at similar angles.	
Vehicles measured	36 (18 angled to the driver's side, 18 angled to the passenger's side)	
Location	Transportation Research Institute, Ann Arbor, MI	
Diagram		A. Center of driver-side front tire to inside edge of guideline B. Center of passenger-side front tire to inside edge of guideline C. Center of driver-side rear tire to inside edge of guideline D. Center of passenger-rear tire to inside edge of guideline E. Driver-side front corner to front parking barrier F. Passenger-side front corner to front parking barrier G. Vehicle length from front-most point to rear bumper H. Vehicle width
Picture		

Table 10. Perpendicular Parking Measurement Information

<table>
<tr><td>Situation</td><td colspan="2">Perpendicular</td></tr>
<tr><td>Definition</td><td colspan="2">The length of the vehicle and parking guidelines are perpendicular to the forward parking barrier. Other vehicles park adjacent to the vehicle on the driver and passenger sides.</td></tr>
<tr><td>Vehicles measured</td><td colspan="2">36 (18 parked against a curb in a parking lot, 18 parked against a wall in a parking garage)</td></tr>
<tr><td>Locations</td><td colspan="2">Parking lot: Transportation Research Institute, Ann Arbor, MI
Parking garage: Thomson Street Structure, Ann Arbor, MI</td></tr>
<tr><td>Diagram</td><td>
</td><td>A. Center of driver-side front tire to inside edge of guideline
B. Center of passenger-side front tire to inside edge of guideline
C. Center of driver-side rear tire to inside edge of guideline
D. Center of passenger-rear tire to inside edge of guideline
E. Driver-side front corner to front parking barrier
F. Passenger-side front corner to front parking barrier
G. Vehicle length from front-most point to rear bumper
H. Vehicle width</td></tr>
<tr><td>Picture</td><td colspan="2"></td></tr>
</table>

FIELD MEASUREMENTS OF PARKING QUALITY – RESULTS

Which Vehicles Were in the Sample?

To facilitate analysis, vehicles were categorized (e.g., compact car, large car) following the scheme of the U.S. Environmental Protection Agency (EPA) in the fuel economy regulations (40 C.F.R. § 600.315-82 (1982)). If the EPA category for a specific vehicle was not listed, a similar vehicle was identified to determine the category.

Table 11 shows the length and width of the vehicles examined, distributed across 12 EPA classes. Only 3 classes contained 10 or more vehicles in this 102-vehicle study. To facilitate further analysis, vehicles were grouped into 2 categories (cars and non-cars) so that the vehicles within the categories were similar in overall size, seated eye height, and rear-end design - factors that were thought to influence parking behavior. Length and width determine how far from the driver a potential contact point with another object is (and can affect the difficulty of making a contact judgment). Increasing the seated eye height, independent of other factors, should make it easier for drivers to see the edges of the vehicle. Certain rear-end designs, such as those in minivans, station wagons, pickup trucks, and SUVs, are constructed so it is easier for drivers to determine where the vehicle ends, which facilitates backing maneuvers.

Table 11. Vehicle Sample Statistics by EPA Vehicle Class

		Length (in)		Width (in)	
EPA Vehicle Class	#	Mean	SD	Mean	SD
Minicompact Car	1	156.0	-	63.5	-
Subcompact Car	7	174.3	13.2	64.9	3.6
Compact Car	29	174.9	5.6	64.4	2.7
Midsize Car	28	186.8	4.7	67.7	3.1
Large Car	5	190.4	11.6	68.2	2.6
Small Wagon	2	162.0	17.0	63.0	0.0
Midsize Wagon	2	177.0	12.7	64.0	4.2
Minivan	8	189.8	8.4	71.4	2.0
Small SUV	4	173.5	3.0	65.3	3.3
Medium SUV	11	177.0	4.4	69.1	3.4
Large SUV	2	190.5	2.1	73.0	1.4
Largest SUV	3	201.3	17.0	74.2	4.3
Overall	*102*	*180.9*	*10.6*	*67.2*	*3.9*

To better understand the data, the entire data set was partitioned into cars and non-cars (mostly SUVs, Figure 3). On average, non-cars were about 4 inches longer (183.7 versus 179.8) and 4 inches wider (70.0 versus 65.9). Longer vehicles tended to be wider, though the relationship was far from perfect ($R^2=0.33$). Since the non-cars were mostly SUVs, their ground clearance was presumably greater.

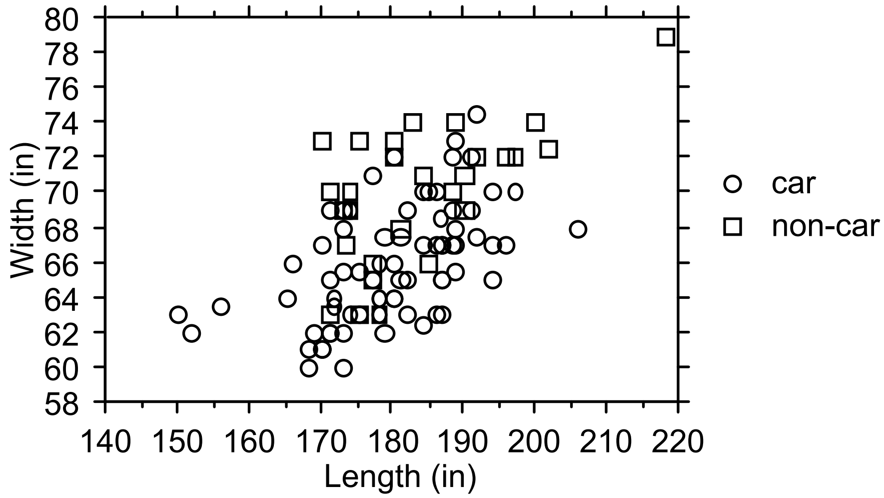


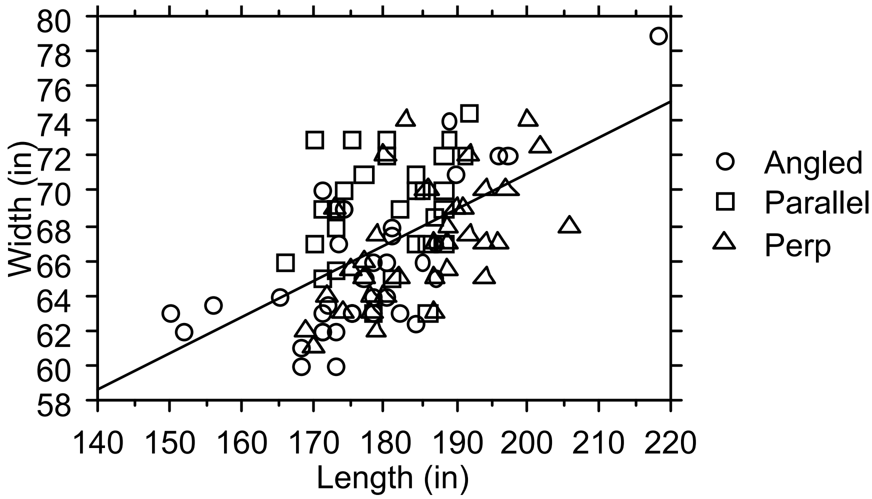
Figure 3. Length and Width of Cars versus Non-Cars

Cars and non-cars were not equally distributed among the 3 parking situations examined, which is not surprising given the modest size of each of the 3 samples (Table 12). Overall the ratio was 3:1 though in production the number of cars and non-cars (trucks, buses, SUVs) now being sold in the U.S. is about 1:1. That ratio slightly overestimates the number of non-cars that could be in a future sample, as medium trucks, heavy trucks, and buses were not encountered in the parking situations of interest.

Table 12. Number of Vehicles Examined for Each Parking Situation

Vehicle	Angle	Parallel	Perpendicular	Total
Car	24	22	28	74
Non-car	12	8	8	28
Total	36	30	36	102

One consequence of the unequal distribution of vehicle types amount the 3 parking situations was that there were statistically significant differences in vehicle sizes in each situation. Using length as the dependent measure ($F(2,99)=5.16$, $p<.01$), with means of 184 inches for perpendicular parking, 180 inches for parallel parking, and 177 inches for angle parking (Figure 4). Given there were relatively more cars in the angle-parking sample, it makes sense that the average vehicle size was less for that situation than the others. The perpendicular-parallel difference could be random variation, or a reflection, to some extent, that perpendicular spots tend to be more accommodating to larger (longer) vehicles, and that drivers may prefer spots appropriate for the size vehicle being parked.



Width(in) = 29.584 + .207 * Length(in); R^2=.319

Figure 4. Length and Width of Vehicles in the 3 Samples

How Well Did Drivers Parallel Park?

How well people park not only depends on the size of the vehicle, but also the size of the space available. For parallel parking, the length of the space matters, determined here by adding the front and rear clearance to the vehicle length. Referring to Figure 5, spaces varied from 209.5 to 455.0 inches long (approximately 17-1/2 to 40 feet long) with a mean of 287.5 inches (about 24 feet). This value is fairly close to the midpoint of the recommended space size listed in the introduction and obtained from the civil engineering literature. The distribution does not appear normal, but is skewed to smaller lengths.

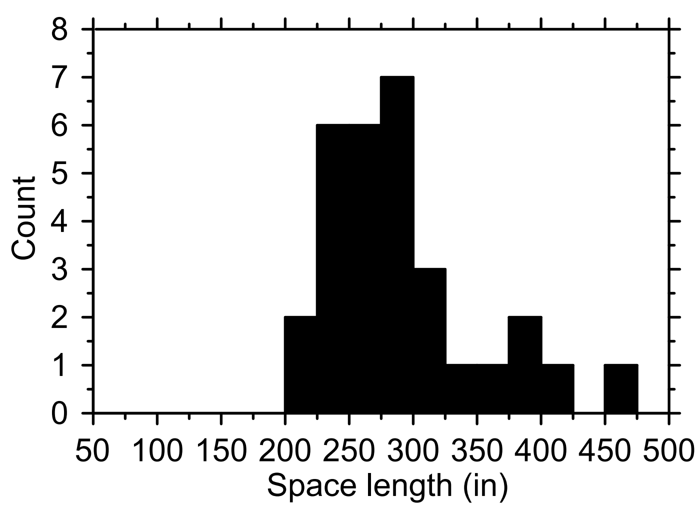


Figure 5. Actual Parking Space Size (Length) Used for Parallel Parking

When people describe how well they parallel park, they consider longitudinal centering in the space ("From afar, does it look like I am in the middle of the space"), how far they are from the curb ("Am I sticking out too far and am I likely to be hit"), and yaw angle ("Is it angled in the space?"). As a practical matter, drivers use the clearance around adjacent vehicles to enter and exit a parking space; so non-central positioning can make parking more difficult for themselves and other drivers. Statistical summaries of the raw data on which these measures are based appear in Appendix E.

As shown in Figure 6, drivers tend to park in the middle of the space (mean of 7.7 inches aft of the middle), though there is a fair amount of variation (49 inches forward to 90 inches behind). The distribution appears to be log-normal.

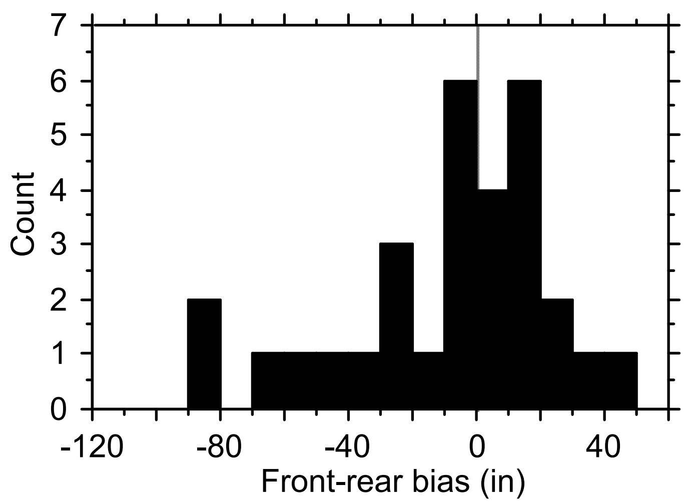
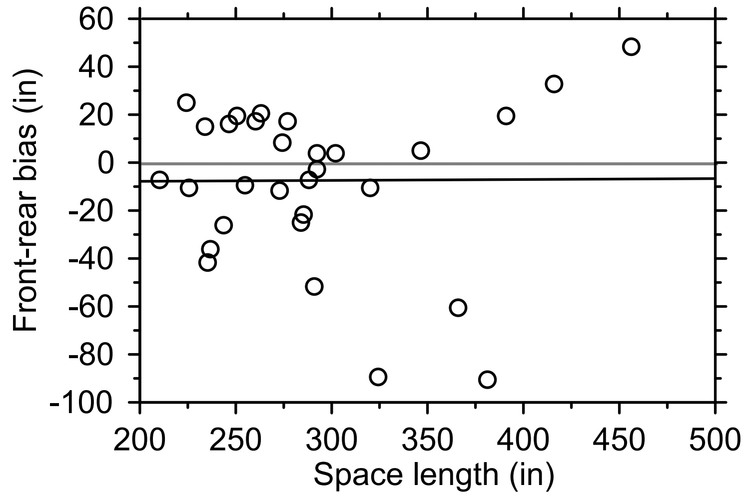


Figure 6. Parallel Parked Front-Rear Bias (inches)
(negative is more space in the rear)

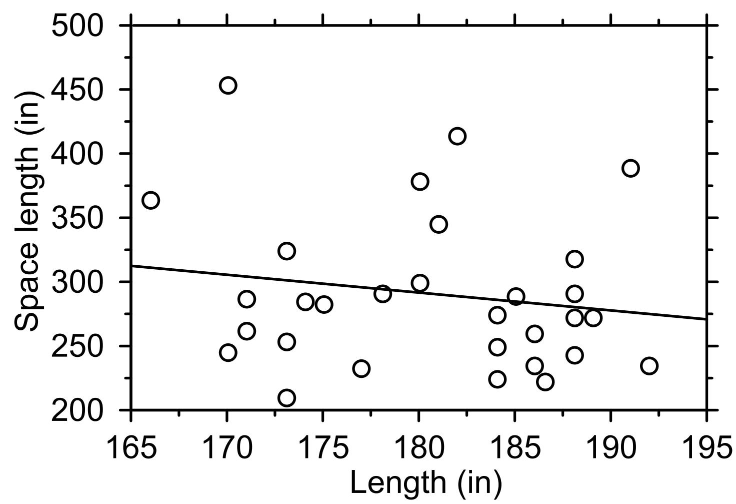
Interestingly, there seems to be almost no relationship between the size of the space and bias. Subjects park somewhat near the middle regardless of the space size (Figure 7).



ront-rear bias (in) = -8.718 + .004 * Space length (in); R^2 = 4.019E-5

Figure 7. Parallel Parking Space Size and Bias

One might hypothesize that parking distances are smaller for larger vehicles because spaces are fairly constant (fixed space hypothesis). On the other hand, one could also hypothesize that parking distances increase (or at least stay the same) for larger vehicles, because drivers of larger vehicles choose larger spaces so their vehicles will fit (bigger vehicle, bigger space hypothesis). Figure 8 shows a weak relationship between vehicle length and end clearance, supporting the fixed-space hypothesis. Interestingly the relationship was weaker for non-cars.



Space length (in) = 551.748 - 1.446 * Length (in); R^2 = .031

Figure 8. Vehicle Length versus Parallel Parking Space Length

The mean distance from the curb was computed as the mean of the front and rear tire distances. As shown in Figure 9, the mean was 4.2 inches with a range of 0 to 13.7

inches for this sample. This distance is somewhat less than the 6 to 12 inches reported as typical in the introduction. Although one would expect an exponential distribution, this distribution appears triangular in shape.

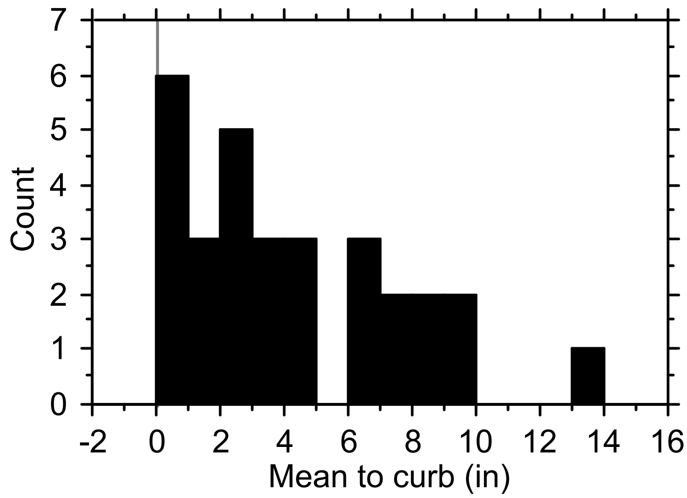
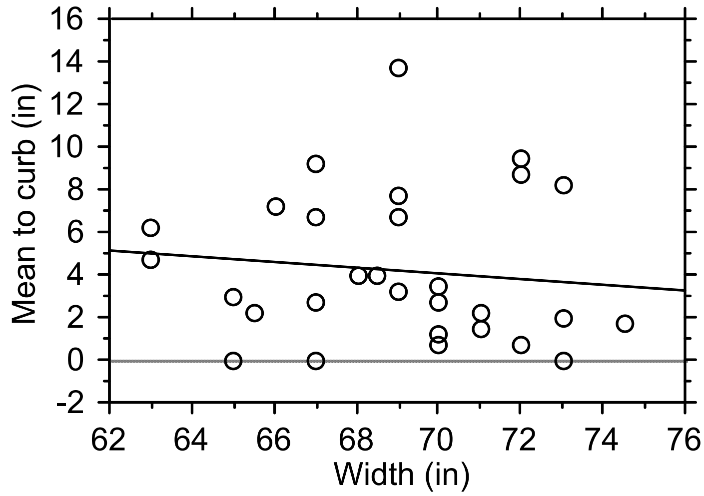


Figure 9. Mean Distance to Curb

It seems reasonable to suggest that distance to the curb could vary with vehicle size, primarily width, with larger vehicles being farther away because the driver is farther from the curb and larger distances are more difficult to judge. On the other hand, if space is viewed as fixed, then larger vehicles should be closer to the curb. The data (Figure 10) indicate there is no relationship, suggesting neither of the 2 hypotheses predominates. When these data are split into cars and non-cars, non-cars are found to park slightly closer (2.7 versus 4.7 inches) to the curb, though the difference is not statistically significant ($F(1,28)=1.89$, $p=.18$).



Mean to curb (in) = 13.722 - .138 * Width (in); R^2 = .015

Figure 10. Distance to Curb versus Width

To determine the yaw angle, the vehicle wheelbase was estimated using a regression analysis based on data for about 20 2003 vehicles listed in Wards Auto World for 2003 (Ward's Communications, 2003). (In that analysis, wheelbase = 30.42 + .41 (length), with that equation accounting for 83 percent of the variance in the data.) As shown in Figure 11, yaw in parallel-parked vehicles was minimal (-3.8 to 3.2 degrees, mean of –0.3 degrees), and appears to be normally distributed.

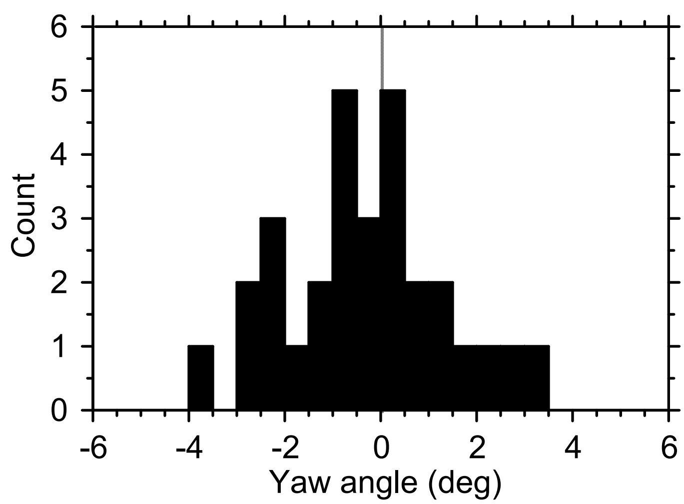


Figure 11. Parallel Parked Yaw Angle (degrees)
(Negative is left.)

How Well Did Drivers Angle Park?

For angle parking, the driver-oriented measures are the distance from the "curb" (longitudinal position), the left-right (lateral) bias, and yaw angle. Do drivers park in as far as possible, placing the bumper over the curb, or do they keep the bumper shy of the curb? Figure 12 suggests the distribution is bimodal with a near zero mean (-0.6 inches) and a large standard deviation (14.1 inches).

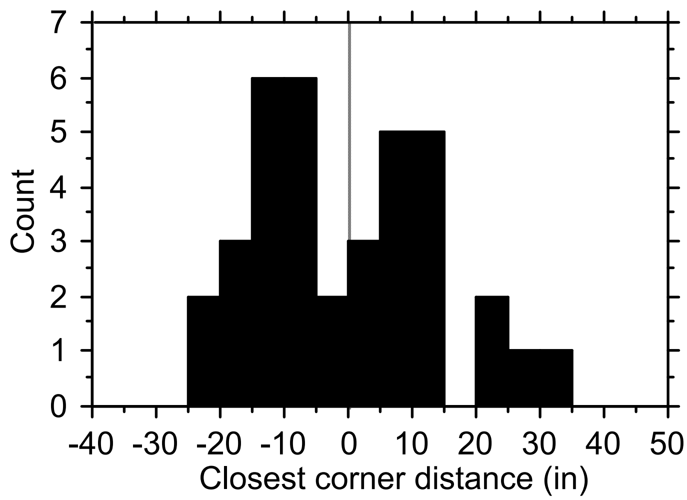
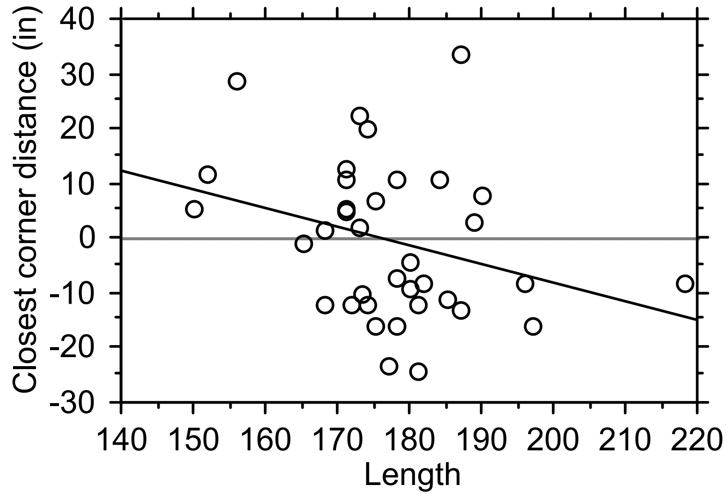


Figure 12. Distribution of Closest Corner Distances of Angle Parking

To help explain why this might occur, the sample was split into 2 groups, depending on whether the bumper overlapped the curb. As shown in Figure 13, the relationship between length and closest corner distance is weak, in part because the sample is composed of a range of vehicle types with different amounts of body styles and ground clearance (Table 13). Similarly, when these data are split into cars and non-cars, there is no statistically significant difference ($F(1,34)=0.43$, $p=.52$), though non-cars are much less likely to overlap the curb (-2.8 versus 0.5 inches).



Closest corner distance (in) = 59.608 - .34 * Length; R^2 = .091

Figure 13. Vehicle Length versus Closest Corner Distance

Table 13. Overlap versus Vehicle Size (number of vehicles)

Vehicle Type	Size	Nonoverlap	Overlap	Total
Large Car	Largest vehicle	0	1	1
Large SUV		1	0	1
Largest SUV		0	1	1
Medium SUV		0	3	3
Minivan		2	2	4
Midsize Car		2	3	5
Midsize Wagon		1	0	1
Small SUV		2	1	3
Small Wagon		1	0	1
Compact Car		5	6	11
Subcompact Car	Smallest vehicle	2	2	4
Minicompact Car		1	0	1
Total		17	19	36

Figure 14 shows the mean yaw angle relative to the parking slot. The mean was 0.2 degrees, very slightly skewed to the right, with a range of -0.8 to 1.1 degrees, a very small range. The direction of entry into the angle slot had no effect on the yaw angle, but entry into angle parking on the right led to yaw angles that were slightly less variable than entry to the left (standard errors of 0.05 and 0.10 degrees). The data appear to be normally distributed.

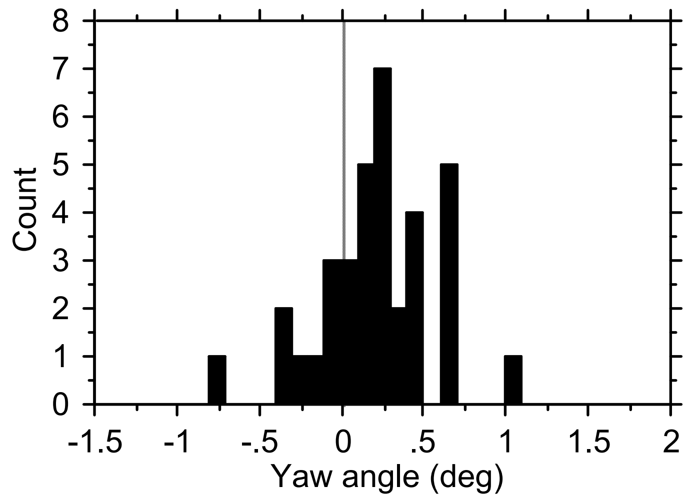


Figure 14. Yaw Angle for Angle Parking

As shown in Figure 15, there was almost no overall lateral bias in parking (mean of .9 to the left, standard deviation of 5.1 inches), though the range (-11.2 to 112.3 inches) was considerable.

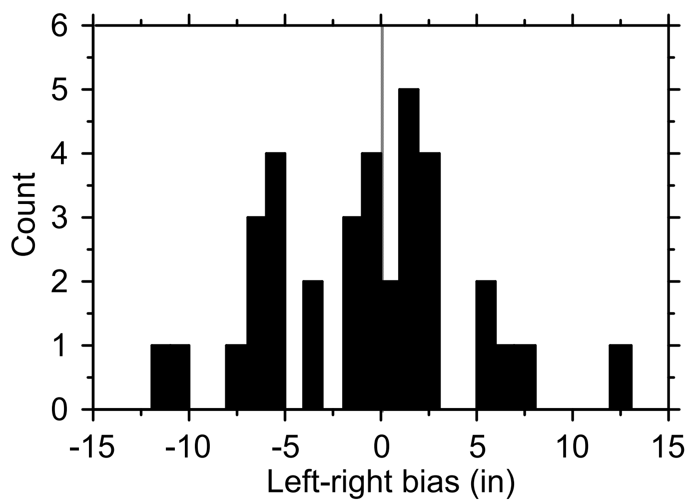


Figure 15. Left-Right Bias for Angle Parking

Figure 16 shows data on the measured space width, not how well people parked. Spaces are specified in half-foot increments. A value of 108 inches corresponds to 8.5 feet with the nearest half-foot increments being 102 inches (8 feet) and 114 (9 feet).

These data suggest the actual and specified values differ by a few inches. However, readers should keep in mind that the actual space width was not measured directly. Rather, the width was estimated from the measured vehicle width, the mean value of the front and rear tires to the painted boundaries, and the width of the painted lines (4 inches). Variability associated with each measurement could explain some of the variation shown in the figure.

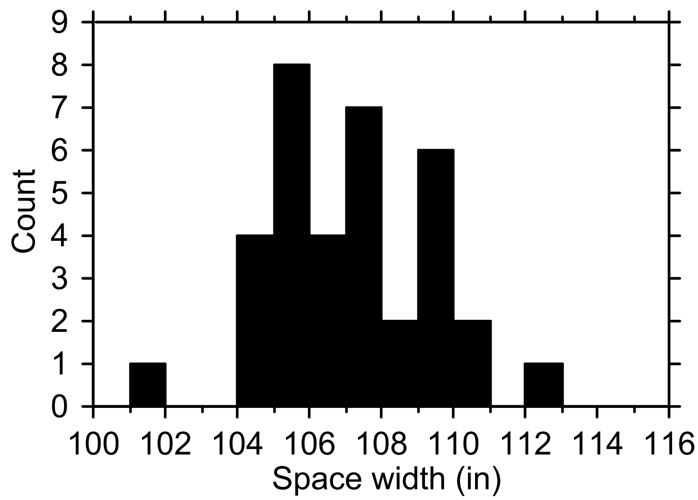
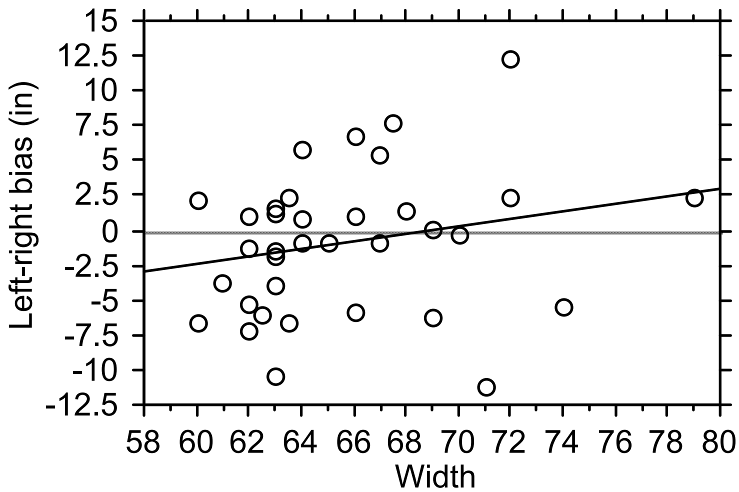


Figure 16. Distribution of Estimated Angle Space Widths

As was noted earlier, lateral position of a vehicle is a compromise of leaving enough space to exit on the driver's side and centering the vehicle in the space. As shown in Figure 17, drivers tend to center the vehicle in the spot irrespective of vehicle width, but there may be a bit more variability with larger vehicles. This could be due to the need to leave space between other encroaching vehicles, adjustments that are more critical for larger vehicles.



Left-right bias (in) = -18.537 + .269 * Width; R^2 = .05

Figure 17, Vehicle Width versus Lateral Position

How Well Did Drivers Perpendicular Park?

For perpendicular parking, the key measures of interest are the distance from the front of the car to the front edge of the spot, left-right centering, and yaw angle. Averaging the 2 front distances together, the mean distance from the bumper to the front of the spot was 4.6 inches, with standard deviations of 12.7 inches. The range was –24.5 to 27.5 inches. However, there were really 2 underlying distributions, with the distance depending on whether a wall was present (Figure 18, mean 13.8 inches) or absent (Figure 19, mean -4.6 inches). If anything, these distributions appear to be normal, but there are far too data points to be certain.

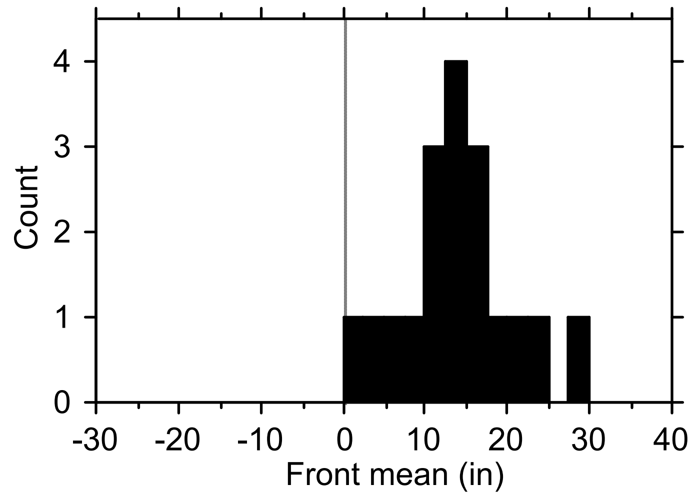


Figure 18. Front Mean Distance when a Wall is Present

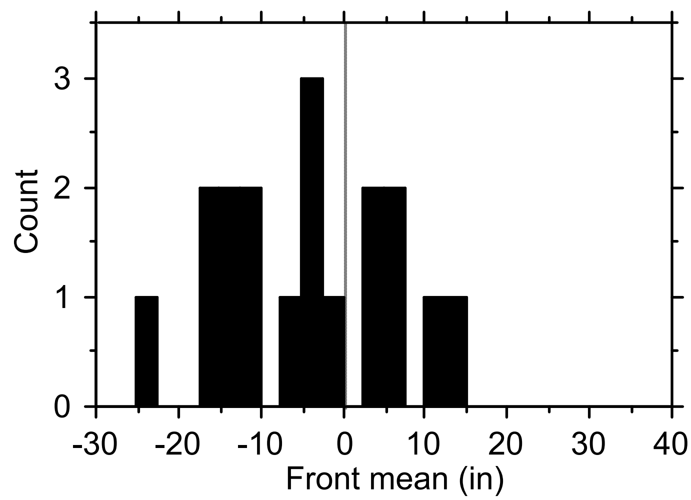
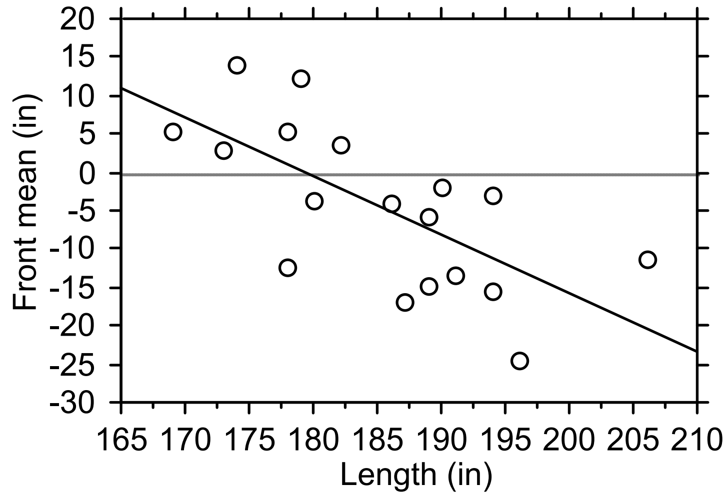


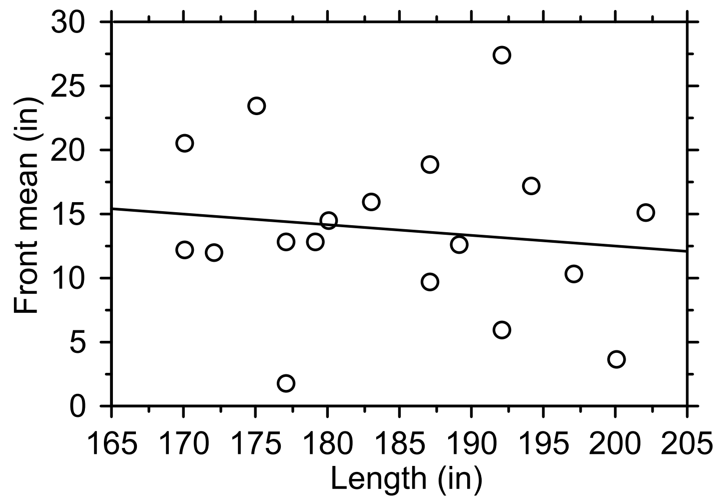
Figure 19. Front Mean Distance when a Wall is Absent

As shown in Figures 20 and 21, the amount of overlap also depends on the vehicle length, varying with vehicle length when no wall is present and being fixed about 14 inches (with considerable variation (0 to almost 30 inches)) when a wall is present. There was no statistically significant difference between cars and non-cars for the no wall present case ($F(1,16)=.52$, $p=.048$).



Front mean (in) = 137.551 - .767 * Length (in); R^2 = .46

Figure 20. Effect of Vehicle Length on Clearance Ahead When No Wall is Present



Front mean (in) = 29.436 - .085 * Length (in); R^2 = .018

Figure 21. Effect of Vehicle Length on Clearance Ahead When a Wall is Present

The width of a parking space (Figure 22) should affect how people parallel park. In this evaluation, the distance from each of the tires to edge lines was measured along with the vehicle width. Using the mean of the distances from the tires to the edge lines plus the vehicle width plus with width of the painted lines (4 inches), space widths ranged from 97.8 to 105.6 inches when no wall was present and from 98.5 to 113.5 inches when a wall was present. For the no wall case, the mean of 101.3 inches is fairly close to the expected 8.5-foot (96-inch) width. For the wall case, the range was 98.5 to 105.6 inches, somewhat more variable but still close to 8.5 feet. Space width was not measured directly and errors from each of the 3 measures could accumulate. Readers should keep in mind that parking was examined in multiple locations and space size can vary among locations.

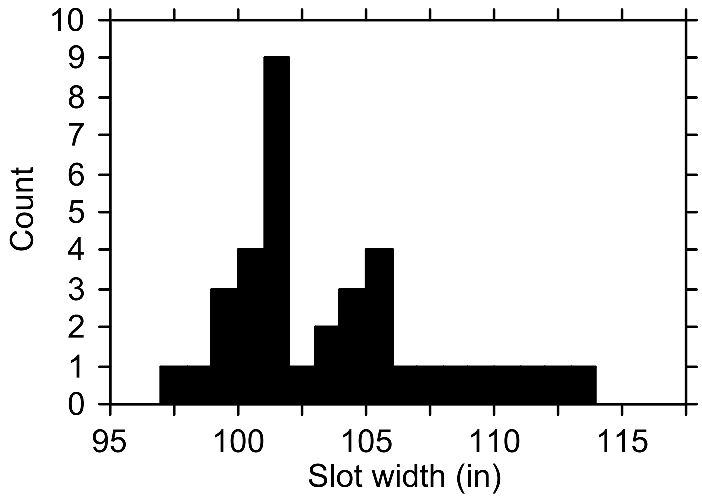


Figure 22. Perpendicular Parking Slot Width

Figure 23 shows the distribution of lateral position values for perpendicular parking. Positive values represent more space on the driver's side than the passenger's side, that is the vehicle is offset to the right. The mean value was -4.1 inches, with the range being -25.5 to 13.4 inches. The lateral position was relatively unaffected by vehicle width (Figure 24). That is, drivers did not make adjustments to allow them for a constant or larger amount of space to exit for larger vehicles. In extrapolating from these results, keep in mind that only a single width spot was examined.

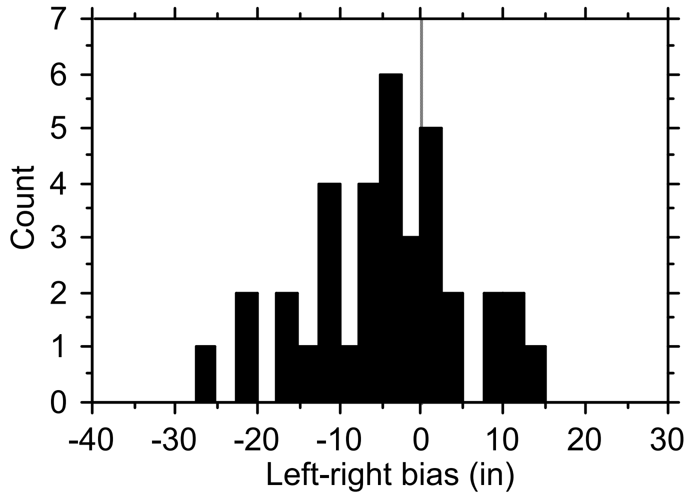
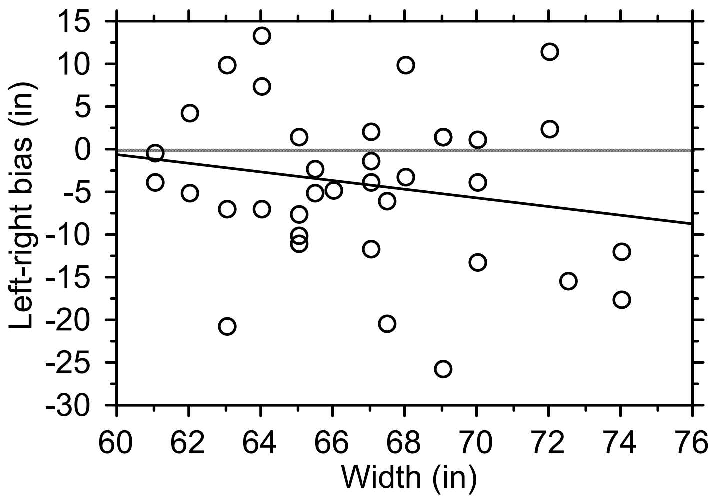


Figure 23. Lateral Position (Left-Right Bias) for Perpendicular Parking



Left-right bias (in) = 30.054 - .512 * Width (in); R^2 = .038

Figure 24. Lateral Bias for Perpendicular Parking

As shown in Figure 25, parked vehicles were well aligned with the parking space (never being misaligned by more than 1 degree) with the mean being 0.1 degrees, which is quite small. The distribution of the data is uncertain.

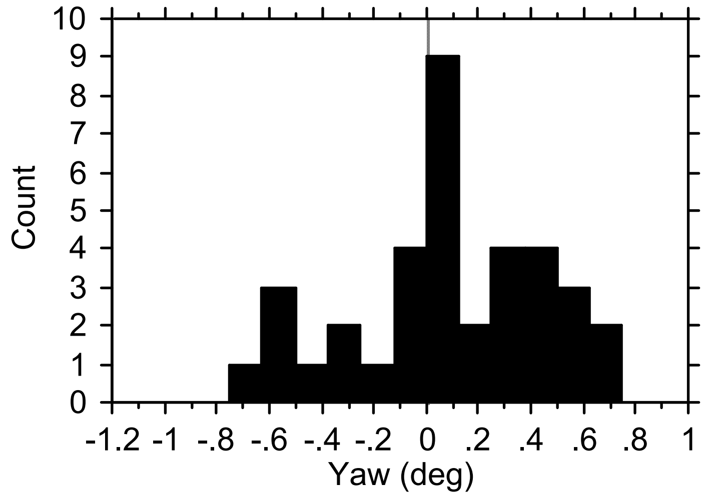


Figure 25. Yaw Angle Data for Perpendicular Parking

SUMMARY AND CONCLUSIONS

1. In what situations do drivers park most frequently?

This question, and the next 3 questions, were addressed by the phone survey. People park about 3 times per day, with the frequency being approximately the same on weekdays and weekends. Approximately 1/3 of the parking was in a lot and another 1/3 involved parking at a residence (with a driveway). The remaining 1/3 was split between commercial parking (at a business or at a school).

More important however, was they type of space utilized in each case. Almost 75 percent of all parking involved perpendicular parking, 17 percent was parallel parking and just less than 10 percent was angle parking. These percentages were fairly consistent across age, gender, and age-gender combinations, though parking maneuvers were more common for middle-aged drivers than for young or older drivers (overall, about 3 per day). There were few differences between weekdays and weekends.

2. What problems do drivers have and what kinds of crashes result?

When asked about problems with parking, about 75 percent of the reports were associated with backing, primarily while exiting a parking spot. Interestingly, of the 8 parking-related crashes reported by the 30-subject sample, and identical percentage of the sample (6 of the 8 crashes), were associated with backing.

3. How well do drivers think they park relative to others?

Half of the sample said they park as rapidly as other drivers, with the percentages of those slower than others and those faster than others being approximately equal. However, 47 percent said they were more accurate than other drivers and an equal percentage said they were the same. Thus, this sample showed a strong bias towards drivers saying they parked “better than others.” It is possible that by chance the random sample include an extraordinary number of drivers who parked well, but that is unlikely.

4. How can parking be improved?

There were many suggestions offered, with the most numerous suggestions being to enlarge parking spaces. Six participants referred to vehicle technology such as cameras.

5. For parallel, angle, and perpendicular parking situations, what were typical values and distributions of values for distances to curbs and space delineations?

There were 3 groups of data that were collected or estimated from the data, (1) vehicle sizes, (2) parking space sizes, and (3) where drivers parked relative to the space boundaries. Table 14 shows the vehicles sizes obtained from the field study. As was noted earlier, there were statistically significant differences in the lengths of vehicles in the 3 data sets with the perpendicular vehicles being largest and the angle vehicles being the smallest, with parallel parking in between. Within and across data sets, longer vehicles tended to be wider, but the correlation was far from perfect. For simplicity, in several analyses, cars and non-cars (mostly SUVs) were considered.

Table 14. Vehicles in Sample

Situation	Value	Mean	SD	Minimum	Maximum
Perpendicular	Vehicle length (in)	184	10	169	206
	Vehicle width (in)	67	4	61	74
Parallel	Vehicle length (in)	180	7	166	192
	Vehicle width (in)	69	3	63	75
Angle	Vehicle length (in)	177	13	150	218
	Vehicle width (in)	66	4	60	79
Overall	Vehicle length (in)	181	11	150	218
	Vehicle width (in)	67	4	60	79

Table 15 summarizes the parking space size data obtained from the field study. The space lengths for parallel parking found in Ann Arbor were consistent with accepted civil engineering practice. Space widths for perpendicular and angle parking were approximately 8.5 feet, though there was some variability in the estimates. Space width should be recorded in future studies.

Table 15. Parking Space Size

Situation	Value	Mean	SD	Min	Max	Dist.
Perpendicula r	Space length (in)	Not recorded	Not recorded	Not recorded	Not recorded	No data
	Space width (in)	108	4	98	114	bimodal
Parallel	Space length (in)	291	60.	210	455	Negative exponential
	Space Width (in)	Not recorded	Not recorded	Not recorded	Not recorded	Not recorded
Angle	Space length (in)	Not recorded	Not recorded	Not recorded	Not recorded	No data
	Space width (in)	107	2	101	112	Normal

Table 16 shows how drivers parked in the field study. When perpendicular parking, drivers parked just over a foot from a wall, if present at the front, though if a ground barrier was present, they overlapped it by 5 inches on average. The range of values was considerable, over 4 feet for this sample.

For parallel parking, drivers tended to leave a bit more room in the rear than in the front (about 8 inches). This may reflect their inability to judge distance to the rear, so the margin for error is larger.

Table 16. Measured Parking Positions in the Field

Situation	Value	Mean	SD	Min	Max	Dist.
Perpendicular	Front distance (wall, no wall) (in)	13, -5	6.4	2, -25	28, 14	Normal, mean varies with wall
	Left-right bias (in)	-4	9	-26	14	Normal
	Yaw angle (deg)	.1	.4	-.7	.7	Uncertain
Parallel	Front-rear bias (in)	-8	33	-90	49	Log-normal
	Curb distance (in)	4	4	0	14	Triangular
	Yaw angle (deg)	-.3	1.7	-3.7	3.2	Normal
Angle	Closest front distance (in)	-1	14	-24	34	Normal
	Left-right bias (in)	-1	5	-11	12	Normal
	Yaw angle (deg)	.2	.4	-.8	1.1	Normal

Laterally, drivers tended to park shifted slightly to the right (by 4 inches on average for perpendicular parking, but only by 1 inch for angle parking), probably so there would be adequate space to exit their vehicle on the driver's side. When parallel parking, vehicles were on average 4 inches from the curb, slightly less than the 6 inches reported in the literature.

Yaw angles tended to be quite small, generally less than 1 degree, with yaw angles being much less for perpendicular and angle parking than parallel parking. For parallel parking, the range was at least triple the perpendicular and angle parking, suggesting that it was much more difficult for drivers to parallel park accurately.

The parking spaces drivers selected did not depend on the size of vehicles being parked. For example, there was no correlation between the length of a parallel parking space and the size of the vehicle in that space. It could very well be that the range of parking space sizes was limited in this sample because only a few locations were examined.

Furthermore, vehicle size did not affect how drivers parked laterally. There were no statistically significant shifts in angle and parallel parking, with drivers attempting to keep a constant amount of exit space on the driver's side of the vehicle. Furthermore, size had no effect on how close drivers parked to the curb. To keep out of traffic, drivers should park wider vehicles closer to the curb. On the other hand, the location of wider vehicles is more difficult to judge, encouraging drivers to park farther from the curb to avoid hitting it.

Vehicle size did affect longitudinal clearance for angle and parallel parking. When no wall was present, drivers were much more likely to overlap a ground barrier when parking a larger vehicle. This could reflect their concern about the vehicle extending too far backward into an access aisle. For smaller vehicles, overlap may risk damage to the vehicle because the ground clearance of the front bumper is small. (Sports cars have much less clearance than full size SUVs.) From a practical perspective, this suggests that seeing barrier clearance could be useful for drivers of small, low vehicles.

Thus, these data provide a reasonable basis for determining reasonable parking space sizes for experimental parking assistance systems as well as baseline data on how well people park. Readers should keep in mind that these data are from a single city with particular requirements for specifying the size of parking spaces. Other places, with different parking-space design guidelines may produce different results. Furthermore, and most importantly, these data reaffirm that the most common parking crash scenario involves backing up from a parking stall, usually in a parking lot, and either striking or being struck by (a) a vehicle driving down the parking aisle or (b) another vehicle backing up.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO) (2001). A Policy on Geometric Design of Highways and Streets, Washington, D.C.: American Association of State Highway and Transportation Officials.

Consumer Reports (2004). Backup Aids, Consumer Reports, October, 69(10), 19-20.

Glanville, J. (1970). Provision, Location and Design of Parking Facilities in Europe, Washington, D.C.: International Road Foundation.

Homburger, W. S. (1982). Institute of Transportation Engineers Transportation and Traffic Engineering Handbook (2nd ed.) Englewood Cliffs, N.J.: Prentice-Hall.

National Academy of Sciences, (1971). Parking Principles (special report 125), Washington, D.C.: National Academy of Sciences, National Research Council, Highway Research Board.

Sill, O. (1968). The Construction of Parking Facilities, Wiesbaden-Berlin, Germany: Bauverlag GMBH.

Smith, D., Green, P., and Jacob, R. (2004). Parking and Low-Speed Crashes: Crash Database, Literature, and Insurance Agent Perspectives (Technical Report UMTRI 2004-9). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Ward's Communications, (2003). 2003 Ward's Motor Vehicle Facts and Figures: Documenting the Performance and Impact of the U.S. Auto Industry, Detroit, MI.

APPENDIX A – PHONE SURVEY OF PARKING FORM

UMTRI
University of Michigan
Transportation Research Institute
2901 Baxter Road, Ann Arbor, MI 48109-2150

Participant number: _____

Parking Frequency Survey Questionnaire

1. What is the make, model, and year of the vehicle you drive most often?

Make: Model: Year:

2. How many hours per day, on average, do you drive?

3. What three locations do you park at most frequently, and what type of parking space are they (90 degree, 45 degree, parallel)?
Note: 90 degree parking indicates parking perpendicular to the previous direction of travel. 45 degree parking indicates parking with less of an angle and vehicle turn than 90 degree parking, and is often utilized on one-way streets (e.g. shopping mall).

	Location	Space Type
1.		
2.		
3.		

4. Do you have more trouble entering or leaving a parking space?

5. For the previous question, does the trouble occur with the vehicle going forwards or in reverse?

6. What makes parking difficult for you?
(Examples: your vehicle, other vehicles and traffic, parking context, yourself)

7. Please describe any parking-related crashes in which you have been involved, if any?

8. How would you rate your parking speed as compared to others?

___Slower ___Same ___Faster

9. How would you rate you parking accuracy as compared to others?

___More accurate ____Same ____Less accurate

10. Please list any suggestions you may have to make parking easier.

11. For the last two weekdays and this past weekend, please list all locations you have parked and the type of parking space involved (straight-in, angled, parallel).

*Note: **Location** is commercial, residential, city, etc. **Where** is garage, structure, street, etc. **Type** is 90 degree, 45 degree, or parallel. **Maneuver** is forward or in reverse*

Weekday 1

	Location	Where	Type	Maneuver
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				

Weekday 2

	Location	Where	Type	Maneuver
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				

Saturday

	Location	Where	Type	Maneuver
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				

Sunday

	Location	Where	Type	Maneuver
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				

APPENDIX B – FIELD MEASUREMENT PROCEDURE NOTES

1. It was assumed that parallel parking was done relative to the adjacent vehicles, and that perpendicular parking and angle parking was done relative to the painted parking guidelines.

2. Prior to obtaining measurements, a vehicle was first observed entering a parallel parking space. This procedure allowed confirmation that the measurements being taken were relative to the actual vehicles present when the parking procedure was performed. This step was not undertaken prior to obtaining perpendicular or angle parking measurements.

3. Vehicle length was measured from the forward-most point to the rear-most point only for parallel parking. It was assumed that anything jutting out from the front or rear of the vehicle, such as a trailer hitch, would need to be considered when performing a parallel parking maneuver.

4. Positive measurements indicate that a vehicle is within the boundaries of a parking space. Negative measurements indicate that some portion of the vehicle was outside the boundaries, such as the front end exceeding the curb.

5. For perpendicular and angle parking, the measurement of the tires was taken along a line perpendicular to the parking guideline to the center of the outer edge of a vehicle tire. The measurement of the corners was taken along a line parallel to the parking guidelines from the forward-parking barrier (such as a curb) to the corner. The vehicles corner was estimated to be the point at which an imaginary tangent line would intersect with a line running parallel to the length or width of the vehicle at a 45 degree angle (Figure 26).

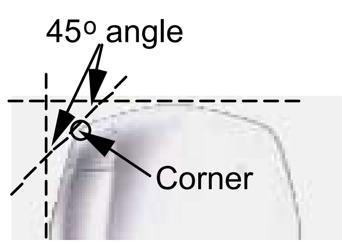


Figure 26. Vehicle Front Corner Determination Technique

APPENDIX C – WHAT MAKES PARKING DIFFICULT

Driver

Perceptual

-Gauging the size of parking spaces
-Low confidence
-Hard to judge if straight in parking space
-Determining bumper-car distances
-Judging sides of parking space

Physical

-Limited motion range
-Arthritis in neck (mentioned 2 times)
-Mobility
-Sore neck from accident

Driver's vehicle

-Visibility (own car is large)
-Large turning radius (mentioned 2 times)
-Maneuvering
-Front end shape
-Long vehicle – judging distances

Other vehicles

-Visibility (other vehicles) (mentioned 5 times)
-Larger vehicles do not leave much room for parking
-Other cars and buses
-Other vehicles being over the line
-Seeing other cars and what is behind when backing out

Parking space

-Proximity of passenger side to other vehicles
-Small spaces
-Narrow parking spaces
-Certain clearance behind
-Difficult to judge distance to other cars/curbs
-Limited space

Other

-Parallel parking when it is to the driver's side
-Pedestrians and children
-Curb for parallel parking
-People who do not park correctly

APPENDIX D – DRIVER SUGGESTIONS FOR IMPROVING PARKING

Parking Spaces
-Larger parking spaces (mentioned 5 times)
-Wider parking spaces (mentioned 9 times)
-Standardize parking space widths (mentioned 2 times)
-Make parking more available
-More visible parking lines
-Better painted lines
-Take away meters
-Don’t use angled parking
-Less curbs in lots to allow for pulling forward
-Mirrors on parking meters to see curb

Vehicles
-Sensors (mentioned 4 times)
-Better turning radius
-Smaller cars
-Moving mirrors
-Better front-end shape
-Camera to see behind car
-Front/side cameras to see parking space

Drivers
-People should slow down
-Better training

APPENDIX E – ADDITIONAL TABLES

Parallel Parking

Table 17 shows the 4 primary measures of parking accuracy for each vehicle. On average, drivers parked about 4 inches from the curb. There was about 4 feet of clearance in front and about 5 feet in the rear. Cars parked farther from the curb than non-cars (1.8 inches for the front tire and 1.0 inches for the rear tire). Cars also were found to be located farther from the vehicles in front of them than non-cars, but closer to the car behind than non-cars. Standard deviations were quite large, ranging from 37 to 113 percent of the mean. For many human performance studies, half of the mean is common.

Table 17. Typical Distance Values for Parallel Parking Maneuvers

Vehicle Class	#	Front Tire-to-Curb Distance (in)		Rear Tire-to-Curb Distance (in)		Front End Distance (in)		Rear End Distance (in)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cars	21	5.0	3.6	4.1	4.4	53.3	40.8	57.9	36.7
Non-Cars	9	3.2	3.2	3.1	3.5	46.7	17.4	61.6	33.6
Overall	30	4.5	3.5	3.8	4.1	51.3	35.2	59.0	35.3

Angle Parking

For angled parking, 6 distances were obtain that specify how well a driver parked, (1) driver-side front corner-to curb, (2) passenger-side front corner-to-curb, (3 and 4) driver-side front and rear tire-to-line distances, and (5 and 6) passengerside front and rear tire-to-line distances. Tables 18 and 19 present mean and standard deviations for the vehicle sample split by cars and non-cars for these distances.

Table 18. Typical front corner distance values for angled parking maneuvers

Vehicle Class	#	Driver-Side Front Corner (in)		Passenger-Side Front Corner (in)	
		Mean	SD	Mean	SD
Cars	22	14.3	16.6	13.3	24.2
Non-cars	14	11.4	16.3	14.1	19.6
Overall	36	13.2	16.3	13.6	22.2

Table 19. Typical Tire-to-Line Distances for Angled Parking Maneuvers

Vehicle Class	#	Driver Side				Passenger Side			
		Front-tire Distance (in)		Rear-tire Distance (in)		Front-tire Distance (in)		Rear-tire Distance (in)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cars	22	18.0	5.4	18.0	5.7	20.2	5.3	21.3	5.6
Non-cars	14	17.0	4.8	17.4	6.2	18.2	6.0	18.1	6.4
Overall	36	17.6	5.1	17.8	5.8	19.4	5.6	20.0	6.0

On average, cars and non-cars were found to park similarly in terms of front corner distances from the curb. The data were averaged across all angled parking (18 angled to the driver side; 18 to the passenger side), resulting in equal representation of each parking situation for the entire vehicle sample. Cars were found to be located farther from the driver-side and passenger-side lines than non-cars, but that is to be expected, as cars on average were smaller in size than non-cars.